A MODEL FOR BUILDING A MOBILE APPLICATION FOR INDOOR NAVIGATION

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ABSTRACT. In today's fast-moving world, people's ability to navigate quickly and effectively in an unfamiliar environment is essential. Using wireless technologies such as Wi-Fi or Bluetooth, moving objects can be traced as well as navigated. The current report offers a brief analysis of modern technologies and methods for determining location. It also provides algorithms that are used for navigation and location. The work includes a model for creating a mobile application for indoor navigation where GPS signals are hard to detect. A graph is used to describe the object, and a QR code is employed to locate the user. The research is aimed at the Laboratory Unit at the University of Mining and Geology "St. Ivan Rilski", but it can be applied to any type of building.

Keywords: navigation, location, Wi-Fi, QR code

МОДЕЛ ЗА ИЗГРАЖДАНЕ НА МОБИЛНО ПРИЛОЖЕНИЕ ЗА НАВИГАЦИЯ В ЗАКРИТА СРЕДА

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РЕЗЮМЕ. От съществено значение в днешният забързан свят е възможността хората да се ориентират бързо и ефективно в непозната среда. Използвайки безжични технологии като Wi-Fi или Bluetooth могат да бъдат проследявани движещи се обекти, както и да бъдат навигирани. В настоящият доклад ще бъде направен кратък анализ на съвременните технологии и методи за определяне на местоположение, както и алгоритми прилагащи се за навигиране и локализиране. Разработката включва модел за създаване на мобилно приложение за навигация в закрита среда, където GPS сигналите са трудно доловими. За описание на обекта ще се използва граф, а за локализация на потребителя QR код. Изследването е насочено към Лабораторен блок към Минно-геоложки университет „Св. Иван Рилски", но може да бъде приложено за всеки тип сгради.

Ключови думи: навигация, локализиране, Wi-Fi, QR код

Introduction

Nowadays, with the evolution of intelligent technologies and when the need arises to determine the location of objects, it has become necessary to employ navigation systems. As the methodology of means to safely and effectively get from one place to another, navigation has been in use since ancient times. The first ideas for navigation information systems (NIS) date back to the middle of the 20th century, but the first practical implementations are from the late 1990s. The development of NIS has been directly related to that of the Internet and network technologies.

Selecting the proper methodology is of extreme importance for building a NIS. A universal methodology to suit all types of project has not been developed yet. Very often, a a particular process necessitates a new methodology based on a specific technology and the related organisational, design, and other considerations.

In the age of information technology, locating an object and determining the shortest path from point to point is easy. Object tracking or route determination can be performed with the help of various software products that employ maps from which user location information and mathematical calculations are derived. These are the so-called location-based services (LBS). They include all satellite navigation systems such as the Global Positioning System (GPS) and the Indoor Positioning Systems (IPS). But these are systems that work eitheronly in an external or only in an internal environment, the latter being more complicated. Yet a more serious challenge is how to track the location of a moving object shifting from external to internal environment and/or vice versa.

In the age of information technology, locating an object and determining the shortest point-to-point path is easy. With the help of various software products using maps, from which user location information and mathematical calculations are derived, object tracking or route determination can be performed. These are the so-called location-based services (LBS). These include all satellite navigation systems such as: Global Positioning System (GPS) and Indoor Positioning Systems (IPS). But these are systems that work only in an external or only in an internal environment, which is more complicated. An even more serious challenge is how to track the location of a moving object, moving from external to internal environment and / or vice versa.

Navigation systems

Global navigation systems are satellites positioned in Earth orbit that transmit signals from various receivers on land. Depending on the satellite system used, the signal strength varies.

The Global Navigation System (GPS) is the navigation system which is used most commonly. When it comes to locating an object or route in an unfamiliar internal environment, this system is unable to operate because the signal emitted by its satellites is lost.

To overcome GPS positioning defects and to achieve accurate positioning in a complex indoor environment, many practical indoor location schemes are introduced, such as infrared connection, WI-FI, Bluetooth, ZigBee, ultrasound, radio frequency identification (RFID), and ultra-wideband (UWB) connection (Cai, X.,2018).

Such systems are called Indoor Positioning Systems (IPSs). With the help of the above technologies based on wireless internet, IPSs detect the current location of an object and in real time determine its coordinates indoors. Typically, such systems are created to facilitate the movement of people in multi-floor buildings or in those with a more irregular structure design, as well as to track objects or people.

Many features exist that make indoor positioning different from outdoor positioning. Compared to the external environment, internal environments seem more complicated because there are many objects (such as pieces of equipment, walls and people) that reflect signals and bring about problems with too many paths and about delays (Alarifi A, 2016).

The technologies which are used to determine location fall into categories concurrently: they are active, as well as passive. Indoor positioning technologies via radio signal or WI-FI fall into the category of “active technologies”, since they require for the object to move and to have some sort of a connecting device. Besides, the devices should be able to collect and process the transmitted information. Examples of systems that employ some of the above active technologies are Ekahau real time location system (RTLS), Microsoft research radar, Intel Place Lab, and others. But only the ultra-wideband (UWB) technology can be used as a passive system as well.

With passive systems, a physical device attached to the moving object should not necessarily be present. An example of such a system is the Device-free Passive (DfP) system. The concept with it is to use an available wireless network for data exchange, to detect changes in the environment, and to track the location of objects passively without requiring additional equipment.

Table 1 presents the criteria wherein wireless technologies can be compared (Brena, Ramon F.,2017, Zheliazkov, G.,2013, Kucarov, St.,2005).

The following conclusions can be drawn from Table 1:

- Each of the technologies presented in the table is standardised;
- Various protocols for data transmission over the network are supported;
- The data transmission rate across the network is about 30Mbps on the average;
- The frequency of the transmitted information is about 2GHz;
- The range of the technologies under consideration is about 100m;
- The deviation yielded by technologies when calculating location is minimum, but it depends on various factors such as visibility between receivers and transmitters, density of access points, etc.;
- The price for implementation and maintenance of the systems is the lowest with WI-FI and BLUETOOTH.

Table 1. *Wireless technologies*

	Standard	Protocols supported	Speed	Frequency band	Range /meter/	Deviation /meter/	Type system	Mean equipment cost	Average maintenance cost	Network
RFID	ISO/IEC 18000-63	ISO 18000-6A/B	Between 27 and 128 Kbps	from 300 kHz to 1 GHz	>100	1-5	active	low	high	mesh
Wi-Fi	IEEE 802.11	Wi-Fi - Access Protocols	54Mbps	2.4 GHz or 5 GHz	Depending on the number AP	<1	active	high	low	*WLAN*
BLUETOOTH	IEEE 802.15.1	UDP/TCP, IPv6, 6LoWPAN	1Mbps up to 2Mbps	2.4 GHz	10-100	0.3 -1	active	low	low	WPAN
UWB	IEEE 802.15.3a	MAC	100Mbps	150 kHz up to 40 GHz	30	0.15	active / passive	low	high	WPAN
ZigBee	IEEE 802.15.4	6LoWPAN, IPv6, PANA, RPL, TCP, TLS and UDP	250Kbps	up to 2.4 GHz	10-100	0.25	active	low	high	*WLAN*

Commercial solutions for indoor positioning

Due to the need to quickly navigate in an unfamiliar environment, many companies around the world offer different solutions for the purposes of saving resources.

Ekahau RTLS (Denis, T. et al.,2006): provides real-time indoor positioning tools developed by the American company Ekahau, Inc. It functions on the principle of the radio signal. The patented software developments are compatible with the various platforms on which the Java language runs, therefore it is possible to develop your own application using the Ekahau Engine.

AT&T Cambridge (Gu, Y. et al.,2009): the technology on which this company’s positioning systems of are developed is UWB. It provides 3-D information on the position orientation and on the orientation of the tracking markers. Users and objects are marked by ultrasonic tags identified as “bats” or active badges.

SpotON (Hightower, J.,2000, Liu, H. et al.,2007): this company’s main concept is to create indoor positioning systems using the power of the radio signal. The focus is more on hardware components (markers, or tags) attached to the object whose location needs to be determined. The objects are located by homogeneous sensor nodes without central control, i.e. Ad-Hoc. SpotON tags use the resulting RSS value as a sensor measurement to assess the distance between the tags.

According to studies, *Microsoft Radar* (Deak, G, 2012) is considered the world's first positioning system based on WI-FI wireless connection. The “fingerprint” method is used to detect the location. This is an offline method which involves recording a radio map of the environment. The *Radar* system calculates the location by monitoring the signal strength of the monitored devices and comparing the values with the records in the database which are employed to create a radio map.

SmartSpace is a modular, open-source location tracking software platform. It has been developed by the Ubisense company. The development makes it possible to interact between the state of people and things in the physical world in real time in order to make the most complex processes visible and controllable.

The *Cisco* company offers an overall solution for object locating via WI-FI through the Cisco Prime Infrastructure system. It allows real-time tracking of objects and detection of their current location with a precision of up to a few metres. This depends on the number of APs. Determining clients' location on the network is calculated by the RSSI and TdoA methods. Cisco Prime Infrastructure works entirely with Cisco hardware components which cost a lot.

Mobile applications for internal positioning:

Navizon is indoor navigation for devices with iOS and Android operating systems. Navizon Indoors is designed to provide location technology with an accuracy of less than one meter. An initial on-site study builds a database of fingerprint signals from the nearby WI-FIs or iBeacons. The mobile applications can then use the created SDK to obtain a high-precision location by combining the fingerprints of the surrounding signal and the output data of all sensors (accelerometer, compass, gyroscope, etc.)

HERE Indoor Radio Mapper is an indoor radio cartographer, an application available on Google Play for Android. It is designed to determine the object location in real time only indoors. It requires a WI-FI and Bluetooth connection with the necessary base access points and a map of the building pre-entered into the device. There are also specific requirements for the installation and use of the application itself.

An application is being developed by scientists from China using the *ZigBee* (Chen, J, 2018) wireless network to determine the location of a classroom. The purpose of this application is to reduce the time it takes students to search for classrooms, as well as for their seats in these rooms. The system uses wireless sensor networks to monitor vacant seats in the classroom. It consists of a monitoring system in the classroom and an information transmission system. The functions of the available seat monitoring system are to calculate the number of people and to transmit this information to the coordinator (the ZIGBEE system, in this case) to process; then it is displayed on an LCD screen

MapsIndoors is a SaaS cloud platform consisting of several components: virtual space (cloud) whose function is to provide input information from the user about the card to be used; MapsIndoors Data AP which makes it possible to retrieve maps from other applications as well; and the SDK application - MapsIndoors app. A card can be embedded in the application by the developers, for consideration, or used for tests. It functions under the Android and iOS operating systems.

A team from the University of National and World Economy in Bulgaria has been developing a static navigation system on the territory of the university. The system works using two numbers written: a hall number for the starting point and a hall number for the terminal station. The path from point A to point B is drawn in the form of an animation on pre-entered maps of the campus with the hall distribution in each building. The system requires initial knowledge of the distribution of university buildings. The application is attached to the university website as a webpage.

Each of the navigation systems under consideration has its own advantages and disadvantages. In general, we can say that currently the GPS is the most popular and developed Global Navigation System. It is used by the majority of the navigation devices of motor vehicles. Regardless of what operating system they are designed for, mobile applications also use GPS navigation to guide objects in an unfamiliar environment. Since this is a satellite system whose signal is transmitted by on-land receivers, any unforeseen obstacle, such as tall buildings and trees, can lead to a route deviation.

Based on the considered technologies for indoor positioning of objects, the following assessment can be made in terms of efficiency, price, and information transmission speed:

- Price: analysis has been made of the most popular technologies for wireless exchange of information for determining the location of objects in an unfamiliar environment. With no infrastructure built, WI-FI ranks the highest in terms of equipment costs. However, with a network already in place, WI-FI technology is the most affordable option to build applications for determining location.

- Speed - the information exchange rate depends on the distance that will be measured from the base point to the desired location. Regardless of the fact that UWB supports the highest data transmission rate, the BLUETOOTH technology has the highest close-range speed.

- Efficiency - UWB technology is with the highest accuracy when determining an object location at short distances indoors. The use of W-IFI technology is appropriate for routes at a greater distance.

An analysis of the existing indoor positioning systems in Bulgaria has been made. It has revealed scarce information about a single company engaged in this activity, but without any details. One of the largest companies in the mining industry with a branch in Bulgaria, *Dundee Precious Metals*, Chelopech, uses special-purpose software products operating with complex mathematical formulae in order to determine the object location via WI-FI connection. Those are expensive programs which the average user would hardly be able to afford.

Methods for object positioning

Each of the technologies listed uses specific methods for calculating the distance between objects or for localising the current location. A number of methods exist that can be applied to static or moving objects in- or outdoors. In general, they can be classified as follows:

- Classical methods for determining the location of objects:

- Odometry
- Absolute and relative localisation
- Triangulation
- Trilateration
- Inertial navigation

- Methods for determining the distance of objects based on radio signals - Other methods for object locating exist that employ the received signal strength (RSS), the angle of arrival (AoA) or the direction of arrival (DoA), as well as the time-of-arrival (TOA) measurements. They are all used to measure the location of objects over a wireless network.

A major problem in determining the route is the movement of the object from point to point, determining its current location, as well as finding the optimum path to the final destination by avoiding probable obstacles along the route. This problem is related to the location of objects and ways to navigate them.

Depending on the chosen technology for locating or navigating objects, it is necessary to carefully consider the methods that will be used. Very often, a technology allows the application of more than one method, especially in wireless networks.

Having considered methods for object localisation via radio signals, it can be claimed that the combination between RSSI and TDoA is more common for greater localisation accuracy. In cases when there is no direct visibility between customer (tag, marker) and transmitters, it is possible to place an additional adapter for the purposes of amplifying the signal.

Each of the considered methods for localisation by means of radio signals works through the joint application of classical methods for determining location as well. The choice of combination between them depends on the environment whereby they will be applied.

In order to obtain higher localisation accuracy and to calculate deviations, as well as influences from various sources of unfavorable signal interferences in the transmission of data over wireless networks, it is necessary to apply familiar mathematical algorithms.

Computer application for navigation in a complex of buildings

Development of methodology

In order to localise an object, its position relative to the surrounding objects needs to be found. If the object is positioned in an outdoor environment, cartographic maps of the area in which it is located can be used. For indoor objects, a map similar to the Fire Evacuation Plans can also be constructed. Such maps are drawn in order to create reference points for finding the position of the object.

Various factors have to be taken into account in the process of developing computer applications for navigating people in an unfamiliar environment. The appropriate navigation technology must be selected according the building. Then, in relation to this technology, the methods must be taken into account that are used by it to calculate the distance and the algorithms for determining the path.

Various computer developments exist that are employed in indoor localisation and are commercial solutions; however, the methodology by which they have been developed is not specified.

The following methodology (Fig. 1) is suggested in Eng. Deliyska's dissertation (Deliyska, D., 2020).

Fig. 1. Methodology for building a computer application for navigation within a complex of buildings

Digitisation of the map of the building

The object of the current study are the 1st and 2nd floors of the Laboratory Block at the University of Mining and Geology "St. Ivan Rilski". The available fire evacuation map has been used as a basis and it was updated with the current hall numeration and the refurbishment of some halls.

In order to determine the route along which the objects will move, a map of the building needs to be created.

Each hall visited by students and guests of the building, is considered as an object and is assigned a unique number. Fig. 2 shows a diagram of the 1st and 2nd floors. The starting point for the building is marked in black, the corridors are in yellow, the stairs leading to the groundfloor and the 2nd floor are in orange, and the entrances to the halls and the lecturers' offices are marked in green.

For a clearer view, the height between the floors on the scheme is extended. Such a map could be applied to any type of building.

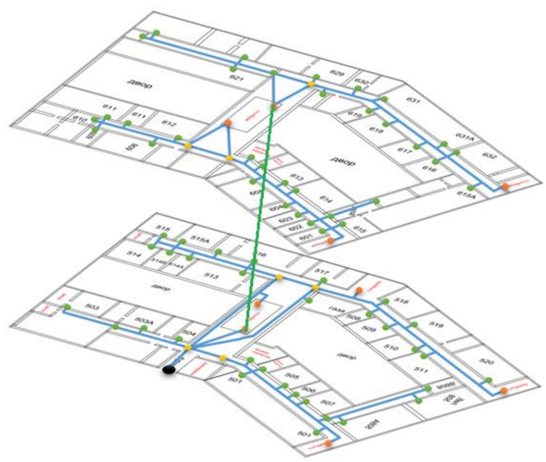

Fig. 2. Schematic presentation of the 1st and 2nd floors of the Laboratory Block at the University of Mining and Geology "St. Ivan Rilski"

The path between the individual objects can be determined by an undirected graph (G) - ordered pair (V, E), with subgraphs for each floor, where: V = {v1, v2, ..., vn} is a finite set of vertices, E = {e1, e2, ..., em} is a finite set of undirected edges; each of its vertices is the halls, the corridors, the staircases, and the ribs edges represent the path between them - k∈E (k = 1,2, ..., m) is an unordered pair (vi, vj), vi, vj∈V, 1 ≤ i, j ≤ n. The node numbers is the actual numeration of the hall (Nakov, Pr., 2012).

If, in addition, function f (i, j) is given that juxtaposes an integer value to each edge (i, j) ∈E, f (i, j) = f (j, i), the graph will be a weighted undirected graph. Peak to peak weights represent the actual distance between the objects in meters (Fig. 3).

	start	Corr1	CorrK2	504	503A	503	Corr-L	WC M	WC F	501	505	506	507	Corr-R
start	∞	1,3	4,7	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Corr1	1,3	∞	6	1,5	6,2	∞	9,8	∞	∞	∞	∞	∞	∞	∞
Corr2	4,7	6	∞	∞	∞	∞	∞	2	9	3,7	11	12,5	16	18,5
504	∞	1,5	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
503A	∞	6,2	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
503	∞	∞	∞	∞	∞	∞	6,7	∞	∞	∞	∞	∞	∞	∞
Corr-L	∞	9,8	∞	∞	∞	6,7	∞	∞	∞	∞	∞	∞	∞	∞
WC M	∞	∞	2	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
WC F	∞	∞	9	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
501	∞	∞	3,7	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
505	∞	∞	11	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
506	∞	∞	12,5	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
507	∞	∞	16	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Corr-R	∞	∞	18,5	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞

Fig. 3. An excerpt from the weight matrix for the graph under consideration

The described elements of the map can be represented by an adjacency matrix. This is one of the most common ways to represent graphs.

Other ways to represent the graph describing the building are by using formats such as XML (Fig. 4) and JSON (Fig. 5). These variants are suitable to be embedded in systems that use BigData or NoSQL databases which are connected to the natural evolution of the system under consideration.

Fig. 4. Presentation of a graph in XML format

```
var graph = new Graph(
                [
                    { id:0, go[1], x:639, y:397},
                    { id:1, go[2], x:638, y:313},
                    { id:2, go[0,1], x:808, y:298},
                ]
            );
```

Fig. 5. Example presentation of part of the graph in the JSON format

By traversing the graph, all paths between its two nodes can be found. Breadth and depth marches are used most often for this purpose. When traversing a graph, one can also search for the mathematically optimal path between the source and target vertices. Dijkstra's algorithm is the most suitable to use in this case.

The graph considered has 83 nodes and 3403 edges.

Mobile application development

Android Studio was chosen as the development environment for the mobile application.

The implemented application has a clean design. The identification of the starting point is performed by scanning a QR code. For this purpose, a is free-of-charge QR code must be generated for each hall (vertex on the graph). It must be placed in a place which is convenient for scanning, at the door or in the immediate proximity to it.

The end point identification can be done in two ways:

1. By entering the number (name) of the required hall. For the user's convenience, as well as to ensure the selection of a really existing hall, the marking of the end point is performed through the list menu (Fig. 6).
2. By entering search criteria – the name of the department, laboratory or hall. The end point is selected by clicking on an element (hall) fromthe result returned.

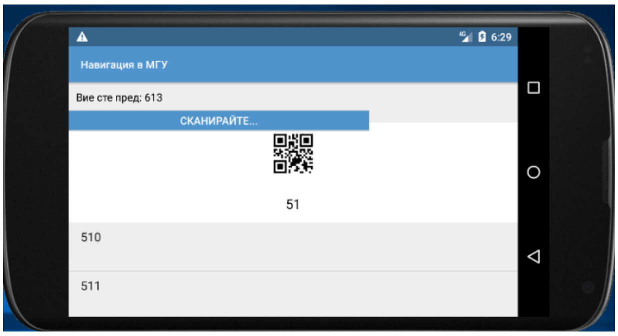

Fig. 6. End point selection

After selecting the start and end point, the shortest path between the two points (halls) is calculated using Dijkstra's algorithm.

The result is visualised using a standard Java graphics library for Android.

Conclusion

According to various studies, most of the Internet traffic around the world has already turned mobile. The number of smart devices is constantly on the increase and significantly exceeds the number of computer users. All this is a prerequisite for the development of mobile navigation systems.

To date, there is no universal system for indoor navigation, nor is there an approach (methodology) for developing such a system.

This report proposes and tests for approval a methodology for creating a navigation system indoors. The system is still being developed, and one of the main problems to be solved in the near future is to upgrade it to a navigation system for combined use in indoor and outdoor environments.

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